Design and Construction of Fixed Bed Pyrolysis System and Plum Seed Pyrolysis for Bio-oil Production

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***Abstract*— This work investigated the production of bio oil from plum seed (*Zyziphus jujuba*) by fixed bed pyrolysis technology. A fixed bed pyrolysis system has been designed and fabricated for production of bio oil. The major components of the system are: fixed bed reactor, liquid condenser and liquid collector. Nitrogen gas was used to maintain the inert atmosphere in the reactor where the pyrolysis reaction takes place. The feedstock considered in this study is plum seed as it is available waste material in Bangladesh. The reactor is heated by means of a cylindrical biomass external heater. Rice husk was used as the energy source. The products are oil, char and gas. The parameters varied are reactor bed temperature, running time and feed particle size. The parameters are found to influence the product yields significantly. The maximum liquid yield of 39 wt% at 520^{0}C for a feed particle size of 2.36-4.75 mm and a gas flow rate of 8 liter/min with a running time of 120 minute. The pyrolysis oil obtained at these optimum process conditions are analyzed for some of their properties as an alternative fuel. The density of the liquid was closer with diesel. The viscosity of the plum seed liquid was lower than that of the conventional fuels. The calorific value of the pyrolysis oil is one half of the diesel fuel.**

***Index Terms*— Energy crisis, Renewable energy, Biomass resources, Pyrolysis technology, bio-oil.**

I. INTRODUCTION

Energy is the key factor for human development. The standard of living and quality of life extensively depends on energy use in industry, transportation, residential, commercial and agricultural. The world primary energy share about 85% [1]. The world reserve to production ratio of primary energy is very low. The rate of energy consumption increasing significantly day by day. The world will not be able to sustain so longer based on current reserves of primary energy. Under such circumstance, the world community needs to search new sources of energy which is sustainable and be able to meet the demand.

Biomass is one of the most important and potential source of energy. It is available, high carbon content, low ash content, low emission, low moisture content and renewable in nature [2]. Among various thermo-chemical conversion processes, pyrolysis is considered as an emerging and attractive technology for liquid oil production due to its simplicity and high conversion capability. Pyrolysis generally defined as the thermal decomposition of organic materials in the absence of oxygen at temperature range of 400-650^{0}C to produce char, tar and gas [3]. The conversion of biomass into liquid may be either fixed bed or fluidized bed pyrolysis system. Fixed bed pyrolysis method may be considered as a promising option where the feedstock's feed in the reactor and heat is supplied externally. In this work, fixed bed pyrolysis of plum seed was considered for bio oil production. External biomass heater was used to supply heat in the reactor. Nitrogen gas was used as inert gas to make inert environment in the reactor. The reaction pathway of pyrolysis shown in Figure 1.

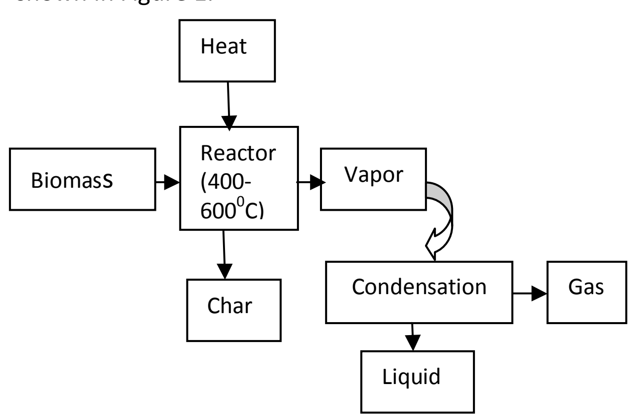

Figure 1. Reaction pathway of pyrolysis process

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Pyrolysis oil can easily transport and burn in thermal plant or gas turbine or upgraded to light hydrocarbon. The solid char can be used as a solid fuel [4].

Most of the developing countries in Asia including Bangladesh have a potential of bio oil from plum seed due to its availability. This carboneous solid waste is renewable energy source and therefore the potential of converting-this into useful energy should be seriously considered. In this way, the waste would be more readily usable and environmentally more acceptable.

II. DESIGN AND FABRICATION

Pyrolysis liquid usually corrosive in nature and the process operating temperature usually about 400-650^{0}C [5]. The major components of the system fabricated by stainless steel of grade AISI 304 due to its rationale properties. The components of pyrolysis system described as follows:

A. Fixed Bed Reactor

Vapor residence time in reactor is an important parameter to achieve maximum yield of liquid. The apparent vapor residence time usually less than 2 second for fast pyrolysis [6]. A cylindrical reactor was designed and fabricated using a stainless steel pipe of internal diameter of 5.08 cm. The gas flow rate was 8 lit/min in the reactor. The reactor volume and length were 600 cm^3 and 30 cm respectively. The dimensional view of fixed bed reactor shows by Figure 2.

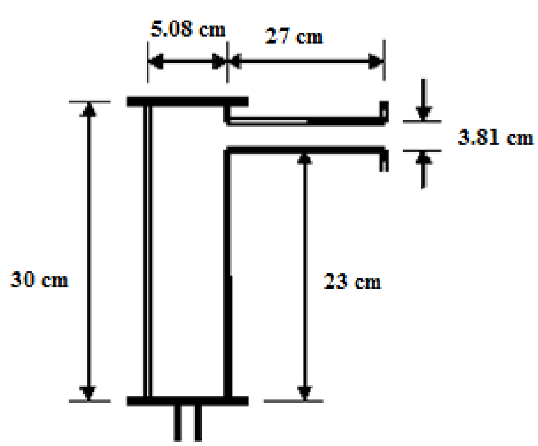

Figure 2. Dimensional view of fixed bed reactor.

B. Condenser

Rapid cooling of pyrolysis vapor influence on maximum product yield.

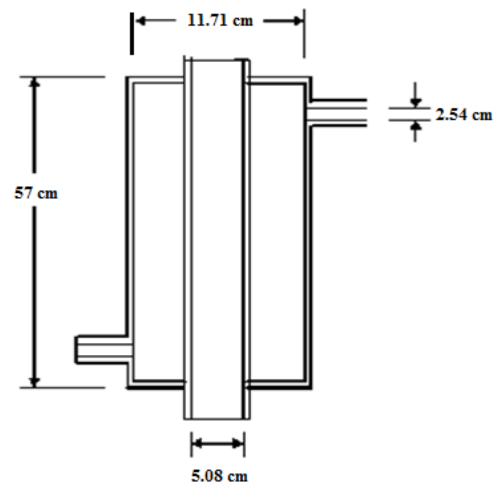

Figure 3. Dimensional view of condenser

An water cooled counter flow condenser used to cool down the pyrolysis vapor. The internal diameter of condenser and length was 5.08 cm and 57 cm respectively. The outer shell diameter of condenser was 11.71 cm. The dimensional view of condenser shown in Figure 3.

C. Gas Flow Meter

Nitrogen gas is available and cheaper was used to make inert environment in the reactor. A multi-stage nitrogen gas pressure regulator of model MUREX N-10 was used to control and regulate the gas pressure from cylinder. The outlet gage was set at atmospheric pressure. A nitrogen gas flow-meter of model MUREX - 0011 with a variable control valve of capacity 6 - 40 liter/min was used to control and measure the gas flow rate. The gas flow rate was set 8 liter/min during the operation.

D. Thermometer

A mercury thermometer of model A7201QFA was used to measure the reactor temperature of the system. A thermometer of temperature range of 100°C to 650°C was inserted into the reactor from top to bottom portion of the reactor to measure the reactor temperature.

E. Construction of Pyrolysis System

The individual components assembled on an angle bar mild steel structure. Screw and flange were used to join the components. The joints were sealed by liquid gasket. An external heater was set on a rack of frame to supply heat in the reactor uniformly. The reactor was connected with N_2 gas (inert) cylinder by pipe. The liquid and char yield separated after cooling and disassembled the system in every operation. The component parts were cleaned and dried before reuse in the next operation. The assembly diagram shown in Figure 4.

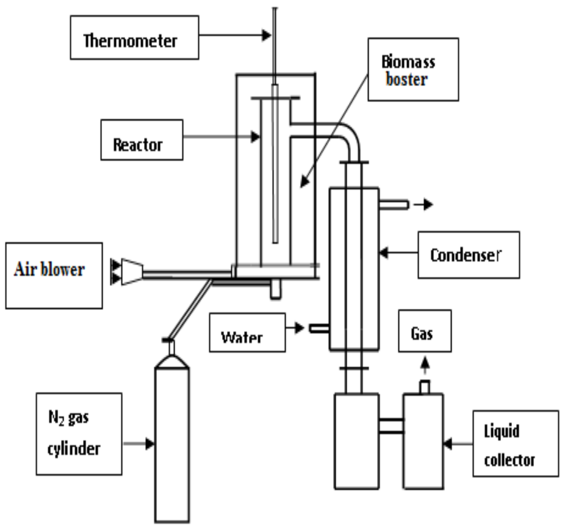

Figure 4. Fixed bed pyrolysis system schematic diagram

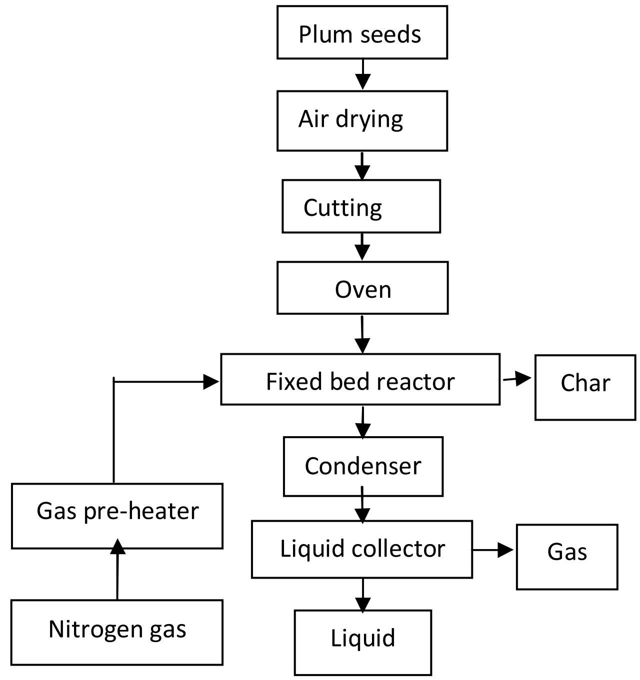

Figure 5. Fixed bed pyrolysis process flow diagram

III. Material And Method

A. Materials

The available Plum seed was collected locally at Rajshahi, Bangladesh. The seed was made in different feedstock sizes like 2.36-4.75 mm, 4.75-6.35 mm and 6.35-9.53 mm. The feedstock was dried in oven for 12 hrs at 110^{o}C to remove moisture before start the pyrolysis process.

B. Method

A biomass based external heater used to heat the reactor. The air flow controlled by means of air blower. The reactor temperature controlled by supply of air. A thermometer used to measure the temperature of fixed bed reactor. The inert atmospheres in the reactor maintained by supplying nitrogen gas and allow to dispose of the pyrolyzed vapor to the condenser. A gas flow meter used to measure the gas flow rate. The vapor condensed in the condenser and collected in the liquid collectors. Non-condensed gas produced in the pyrolysis process and flared to the atmosphere. The process flow diagram given in Figure 5.

IV. Results And Discussion

A. Product Yield

Liquid, solid and gas is the product obtained from plum seed pyrolysis process. A maximum of 39 wt% oil obtained from plum seed fixed bed pyrolysis process with particle size of 2.36-4.75 mm at reactor temperature of 520^{o}C.

B. Effect of Operating Temperature on Product Yield

Figure 6 illustrates the variation of product yield with operating temperature with feed particle size of 2.36-4.75 mm. From figure, it is seen that at low and high temperature the liquid yield was lower compare with intermediate temperature. The char yield at low temperature was higher and decreasing with increasing temperature. The gas yield was high at higher temperature. The maximum liquid obtained at 520^{0}C. The reason of this trend due to pyrolysis devolatization reaction does not appear at low temperature and it needs reasonable temperature to volatization. Besides, further increase in temperature causes secondary reaction of vapor yielding more gas.

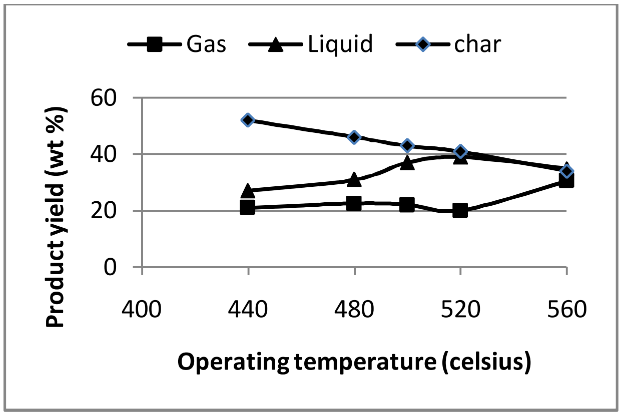

Figure 6. Effect of operation temperature on product yield.

C. *Effect of Feed Particle Size on Product Yield*

The variation of product yield (wt %) with feed particle size illustrates in Figure 7 at reactor bed temperature of 520^{0}C and operating time of 120 minutes. From figure, it is seen that the maximum liquid yield (39%) achieved for a particle size of 2.36-4.75mm at 520^{0}C reactor bed temperature. The trend of liquid yield decreasing with increasing particle size due to the cells of larger size particle not able to heated up sufficiently within a short time and causes incomplete pyrolysis.

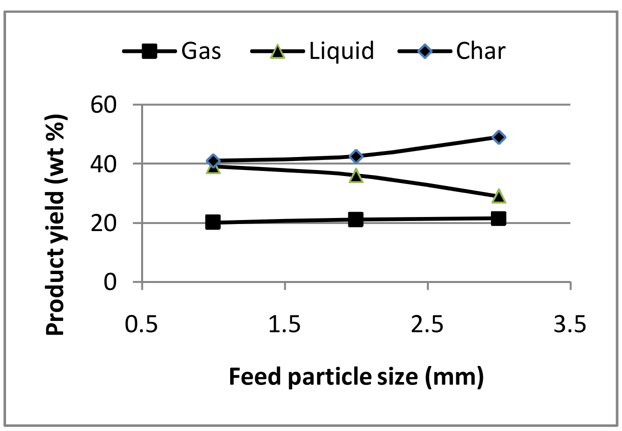

Figure 7. Effect of feed particle size on product yields (520^{0}C reactor temperature).

D. *Effect of Running Time on Product Yield*

Figure 8 illustrates the variation of product yield with running time at 520^{0}C reactor bed temperature and particle size of 2.36-4.75 mm. Figure shows the maximum liquid product is 39 wt% of biomass feed and the solid char product is 41 wt% at 120 minutes. Higher or lower than that of 120 min will causes decrease the liquid yield. This is due to insufficient pyrolysis reaction and higher rate of gas discharge.

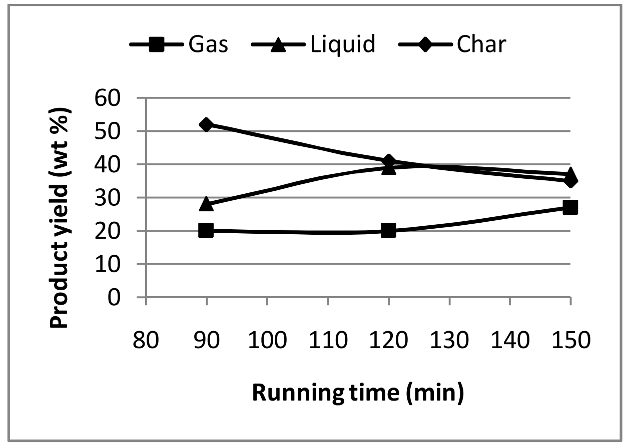

Figure 8. Effect of running time on product yield (520^{0}C reactor temp., 2.36-4.75 mm particle size)

E. *Physical Property Analysis of Pyrolysis Oil*

The higher heating value of oil found to 22.39 MJ/kg. The heating value is low due to the presence of moisture and oxygenated components. The density of oil found to 940 kg/m^3. The kinematic viscosity of oil found to 1.14 cSt at 30 ^{0}C. The flash point 112^{0}C which is quite high. So, the oil can stored at room temperature with safe mode. The pH value of oil found to 3.19 which is quite low.

F. *Comparison among Pyrolysis Oil, Biomass Oil and Diesel Fuel*

The characteristics of plum seed pyrolysis oil compared with other oil derived from biomass and diesel. The comparison shows in Table I and Table II. Comparison shows the density of plum seed liquid is closer to diesel. The viscosity of plum seed liquid is lower than that of the conventional fuel. The calorific value is much lower than that of conventional fuels.

TABLE I. COMPARISON OF PLUM SEED PYROLYSIS OIL WITH BIOMASS DERIVED PYROLYSIS OILS

Parameter	Plum seed oil	Waste paper oil [7]	Sugarcane bagasse oil [2, 10]	Jute stick oil [2, 8]
KINEMATIC VISCOSITY AT 30^{0}C	1.14	2.00	13.80	12.08

(CST)				
DENSITY (KG/M^3)	940	1205	1160	1224
FLASH POINT (^{0}C)	112	200	105	>70
HHV(MJ/KG)	22.4	13.10	20.072	21.09
PH VALUE	3.19	1.5	2.98	2.92

TABLE II. COMPARISON OF PLUM SEED PYROLYSIS OIL WITH DIESEL FUEL

Parameter	Plum seed oil	Diesel [8]
KINEMATIC VISCOSITY AT 30^{0}C (CST)	1.14	2.61 at 20^{0}C
DENSITY (KG/M^3)	940	827.1
FLASH POINT (^{0}C)	112	53
HHV(MJ/KG)	22.39	45.18
PH VALUE	3.19	-

V. CONCLUSIONS

The thermo-chemical conversion, successfully converted plum seed into liquid, char and gas by pyrolysis technology. The fixed bed pyrolysis of plum seed has a maximum oil yield of 39 wt% of biomass feed with particle size of 2.36-4.75 mm at a reactor bed temperature of 520^{o}C and the maximum char is 52 wt% at 440^{o}C at a gas flow of 8 liter/ minute with the running time of 120 minute. The pyrolysis liquid derived from plum seed is compared for its physical and fuel properties with other biomass derived oil and diesel fuel. The oil is acidic in nature. The flash point of the oil is higher than that of diesel fuel. The heating value of the oil is found to be similar to that of other biomass derived oils, but much lower than that of conventional fuels. The oil may further be upgraded for better fuel properties.

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